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Case Studies in Forensic Geotechnical and Foundation Engineering

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ABSTRACT

Forensics in the geo-domain encompasses an extensive array of topics with specific emphasis in geotechnical related fields. A new discipline known as forensic geotechnical engineering (FGE) has been created to deal with investigations of soil-interaction related failures of engineered facilities or structures. A practicing geotechnical engineer cannot provide services without the fear of a lawsuit. Services of geotechnical engineers experienced in jurisprudence system are commissioned to investigate such failures.

This paper presents two case histories where forensic geotechnical engineering was effectively utilized to identify, investigate, and remediate the problem as well assist in litigation. The first case history identifies a request from an office building owner for a forensic geotechnical engineering review of an extensive distress settlement cracking claim. The claim resulted in discovery of a relic sinkhole with neither collapse nor an injury combined with deficient foundation and slab design. The second case history illustrates how a forensic geotechnical investigation was undertaken to identify causative factors of the slope failure and to address the extent of damage.

In both cases, the project owner(s) were able to recover a major portion of the loss and litigation cost from the insurance company.

LEGAL AND ETHICAL ASPECTS OF FORENSIC GEOTECHNICAL ENGINEERING

A new discipline known as forensic geotechnical engineering (FGE) has been created to deal with investigation of soil-interaction related failures of engineered facilities or structures. Services of forensic geotechnical engineers are generally commissioned to investigate such failures. "What happened?", and "Why did it happen?" are usually the first two questions asked of the forensic engineer. Of course, these are then followed by, "How can it be fixed?", and all too often, "Who's fault is it?", and "Who is going to pay?" (Bell, 2007)

FGE prepares civil engineers to read, think, speak, and analyze like a lawyer. In addition, it familiarizes him with the jurisprudence system so that he is more able to understand and deal with legal issues since he/she has to work closely with statutes and regulations, may become involved in litigation, or who may serve as an expert witness.

Engineers should perform services only in the areas of their competence and they should undertake assignments when qualified by education and/or experience in the specific fields involved. Direct examination is an expert's opportunity to persuade the jury that his/her opinion should be believed. The goal during direct testimony is to persuade the jury to find one's opinion credible. To connect with the jury an expert needs to understand what jurors want and employ the best ways to communicate with them.

The legal considerations of these forensic geotechnical engineering services illustrate the reality that the engineering investigation of a failure incident is a fact-finding mission that results in uncovering the probable causes of that failure. It concentrates on the identification of hidden clues. The procedures adopted for the analysis, testing, opinions, and written reports should be able to satisfy even legal scrutiny of their validity.

Well over 90% of civil cases settle prior to expert witnesses being called for a trial. As such experts can expect that the majority of testimony that they give will be given at deposition. Accordingly, the experts need to excel during their depositions as they are a key element of the discovery process.

If the expert witness is a litigation consultant he/she is not subject to discovery by the opposing counsel. If disclosed as an expert then he/she is subject to discovery by the opposing counsel.

CASE HISTORY ONE

This case history identifies a request received from a building

owner for a forensic engineering review to investigate a situation where a severe site specific soil-structure deficiency occurred and caused post construction damage to an office building in west central Florida. Questions were raised regarding the Evaluations were also made to see if repairing or replacement of the structure was, in fact, necessary.

A case history is presented where:

1. the building structure was damaged and stability of the structure was threatened.

2. the owner filed a claim against the developer/builder/designer/geotechnical engineer for negligence and for not informing them of a potentially unstable pre-existing condition.

3. the owner hired a Forensic Geotechnical Engineer (FGE) to investigate, remediate, and assist in litigation as well as serve as an expert witness on an "as needed" basis.

4. the developer/builder/designer offered a band-aid cosmetic repair solution that the owner then rejected upon the advice given by the author.

Project Description

Construction of the 40 ft x 70 ft (12.5m x 22.0m) single story concrete block masonry CBS office building was performed and completed as per design plans, permitting, and pre-construction technical support from the civil engineer. Foundation support included installation of 12 inch butt diameter timber piling, driven to 24 tons capacity (as per the pile driving records prepared by a geotechnical engineering representative at the site) along the exterior perimeter grade beam supporting the load bearing walls. The interior slab was a 4 inch thick fiber mesh structural integrity and removal/replacement of the completed structure was considered a viable yet costly option. A forensic geotechnical investigation was undertaken to identify causative factors of settlement distress and to address the extent of damage. concrete supported on compacted soil for the entire building footprint. Work on the building commenced in late 2005 and was completed in June 2006.

Soon after occupying the building, the owner(s) observed certain impacts on their property. Concerns identified by the owner(s) have included:

- noticeable settlement and deflection of the interior soil supported floor slab.

- visible cracks throughout the interior of the building.

- differential settlement of building foundations (exterior piles and interior floor slab) resulting in misalignment of the doors.

- possible damage to the below grade utility lines.

- stability of the supporting structure, resulting from consolidation/decomposition of peat and settlement of a continuing nature.

- substantial deflection distress and development of cracks throughout the interior and foundation floor slab within the office building as a consequence of differential settlement due to the consolidation of existing peat material within the building footprint area. Additionally, total and differential settlement of the foundation support system and resulting distress appeared to be of a continuing and progressive nature.

Figures 1 through 8 illustrate the salient features of the case history and owner's justifiable concern.

Fig. 1. Two close up views of sinking floor at conference room door.

Fig. 2. Close up view of interior partition wall separation from sinking floor slab.

Fig. 3. Close up view of additional separation.

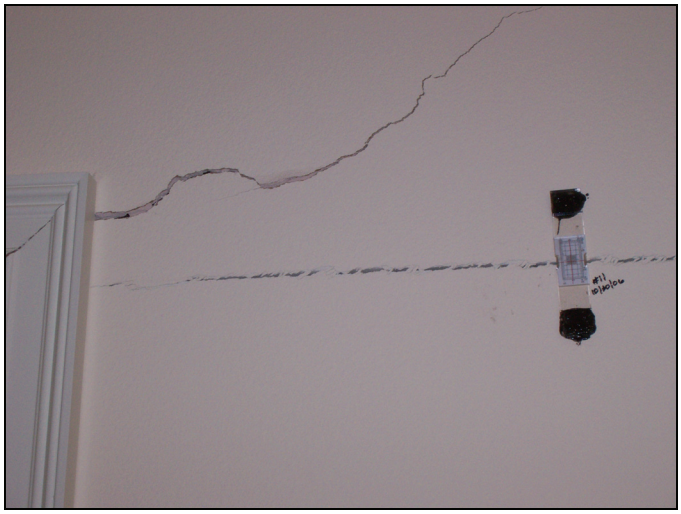

Fig. 4. Close up view of wall crack showing new crack and additional movement.

Fig. 5. View of gage No. 8 showing worsened movement.

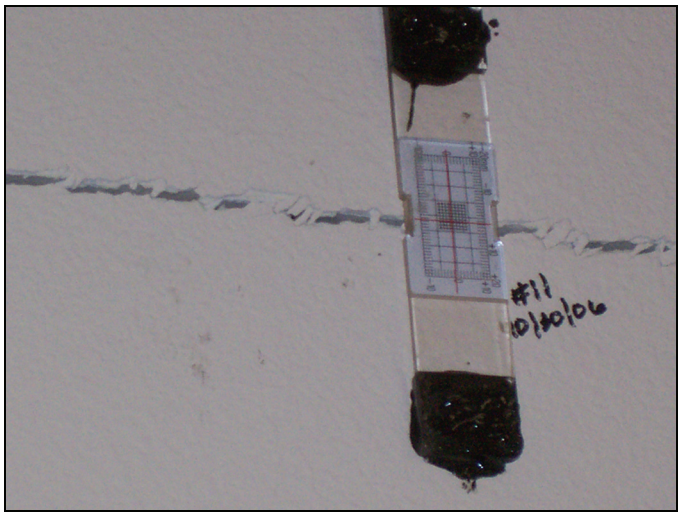

Fig. 6. Gage No.11 in south wall showing worsened movement.

Fig. 7. Close up view of bottom of west side column.

Fig. 8. Separation and sinking of slab along building exterior.

A 2-stage program was carried out by the forensic geotechnical consultant.

Stage 1 Investigation

Stage 1 consisted of a review of the field inspection of the structure, review of the project foundation drawings, and pre-design geotechnical exploration report.

The findings, comments, and conclusions derived from the Stage 1 investigation at the project site revealed that:

1. there were wide spread separations between the walls and the floors, and between partition walls and ceilings. The separations appeared to be greatest toward the center of the building.

2. a floor elevation survey of the building floor slab conducted in March 2007 indicated partial settlement of 3 inches (7.5cms) at the center of the building, as illustrated in Fig. 9.

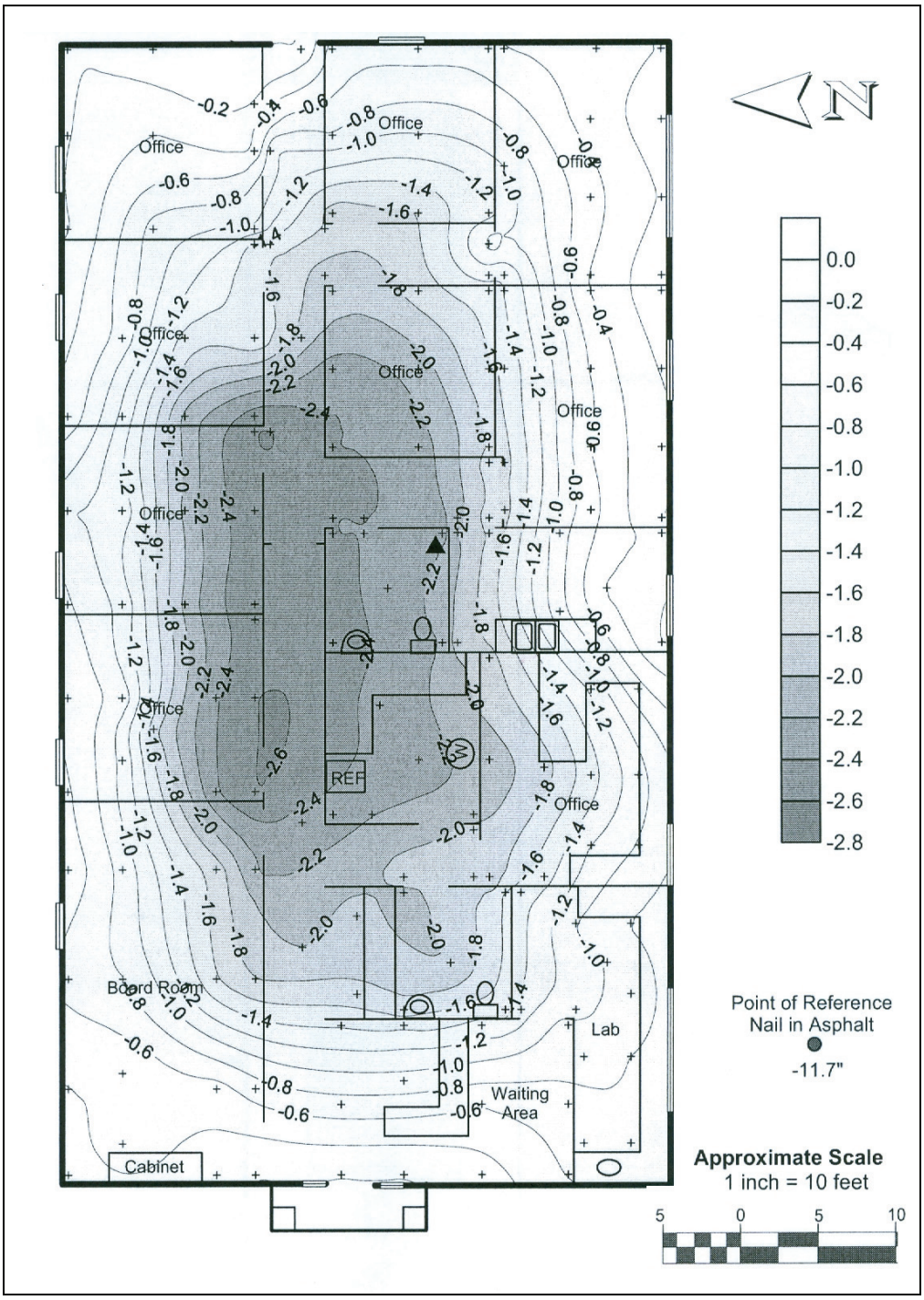

Fig. 9. Floor elevation survey.

3. subsoil test borings performed by the pre-design geotechnical engineer were 40 ft (12.0m) deep and consisted of organic compressive soils. Pressure treated timber piles with an embedment depth of 20 to 25 ft (for a 12 inch butt or 6 inch tip diameter) were utilized and a net allowable capacity of 12 tons was recommended.

4. during construction pile lengths of 50 to 55 ft (16.0m to 18.0m) were used. Furthermore, 12 inch (30.0cm) square prestressed precast concrete (PCC) piles were substituted in lieu of pressure treated timber piles. In addition, the contractor elected to use 30,000 ft lb hammer in lieu of the recommended hammer of not to exceed 18,000 ft lbs for the timber pile.

5. All three of the borings had significant weight-of-rod (WOR) and weight-of-hammer (WOH) zones throughout the infilled soils. In those cases where underlying sandy soils were encountered, it appears that the deep sands were in a more stable condition. This profile may indicate on going raveling associated with the relic sinkhole, or may just indicate that the infilled organic soils are weak and very loose.

6. the interior floor slab was only soil supported and not structural (with interior grade beam supported). Refer to Fig. 10 for a building and foundation layout and test boring (SB-1) location plan.

7. proper pile capacity determination, its installation, and structural grade beam supported floor slab was not performed.

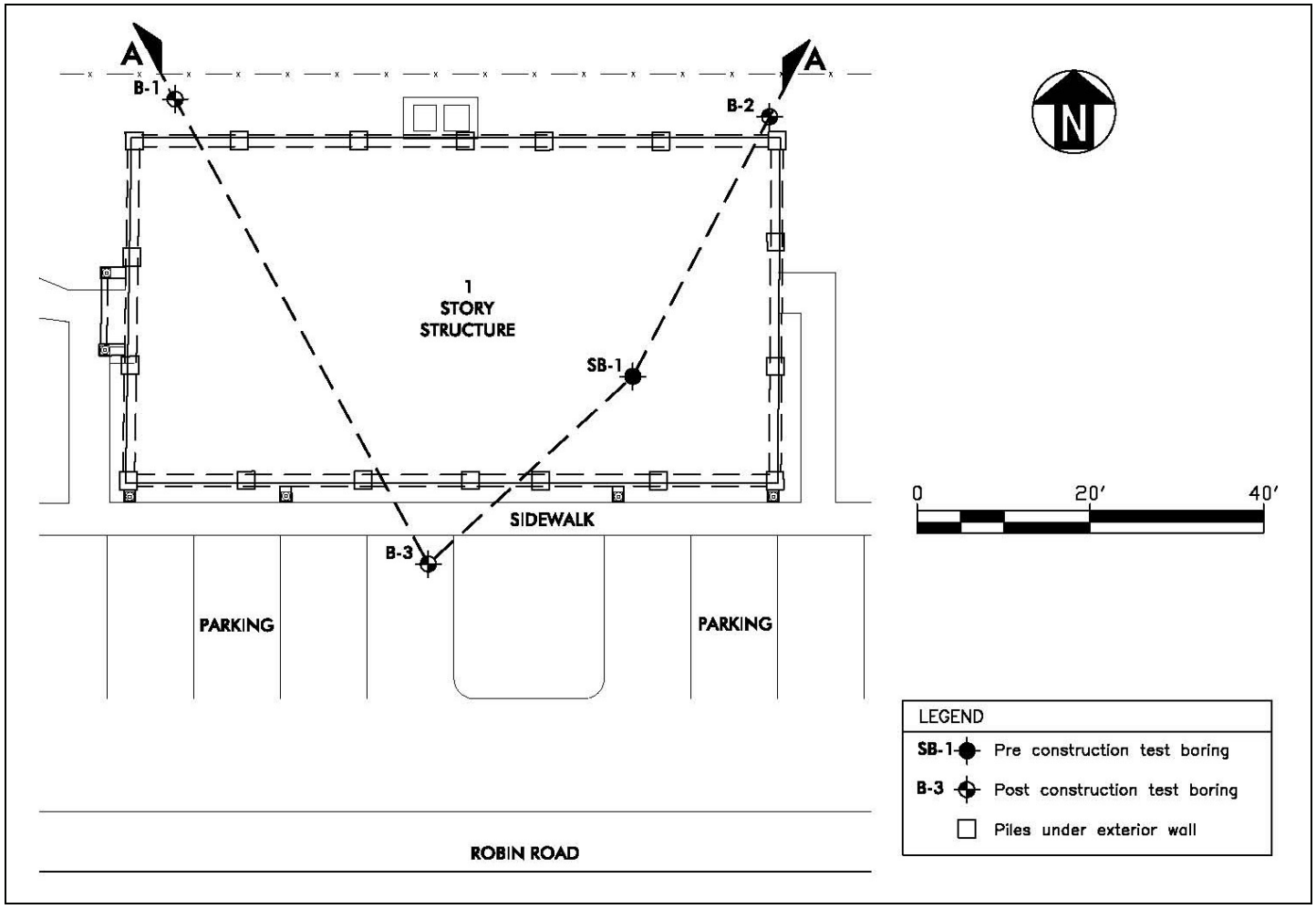

Fig. 10. Building and foundation layout plan with test boring locations.

Stage 2 Investigation

In an effort to properly address, investigate, and evaluate the alleged subsoil deficiency a detailed subsoil exploration program was undertaken by advancing test borings to depths ranging from 130 ft (40.0m) to 190 ft (60.0m). Test boring location plan (with additional test borings; B-1, B-2, and B-3) stratigraphy showing internal erosion and solution features is illustrated in Fig. 9. Site stratigraphy is illustrated in Fig. 10. It consisted of elements listed below.

1. the site was underlain by very poor soil conditions not capable of providing support for any type of construction that assumes bearing to be developed from the underlying soils.

2. upper fill soils were mixed with debris underlain by predominately organic soils with organic content ranging from 5% (at 80 ft depth) to 18.5% (at 60 ft depth) and 85% (at 135 ft depth).

3. no limestone was encountered to the termination depth of 135 ft (43.0m) to 190 ft (60.0m). Project site stratigraphy showing internal erosion and solution features is illustrated in Fig. 11.

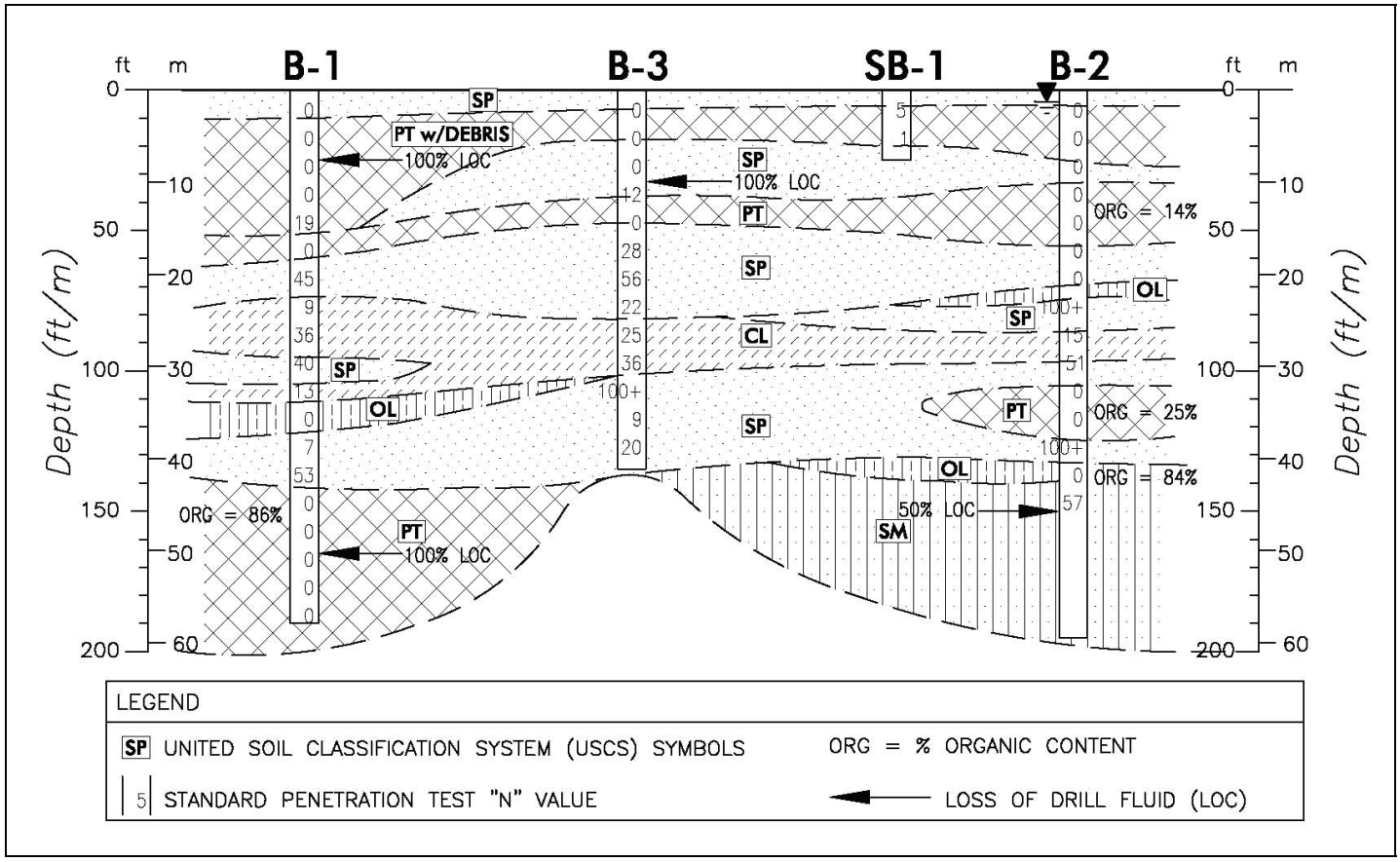

Fig. 11. Project site stratigraphy showing internal erosion and solution features.

4. damage to the building is the result of factors including consolidation of significant factors including consolidation of significant depth of very loose organic soils (located within a large relic sinkhole) along with the consolidation of buried debris located within or just below the develop fill soils and loading street zone.

5. the old aerial photographs from 1941 through 2005 showed the wetland feature and confirmed that the building was constructed in a wetland drainage basin area over deposits of very deep, very loose organic soils. An aerial of the property taken in 1952, with the building and overall project site superimposed, is illustrated in Fig. 12.

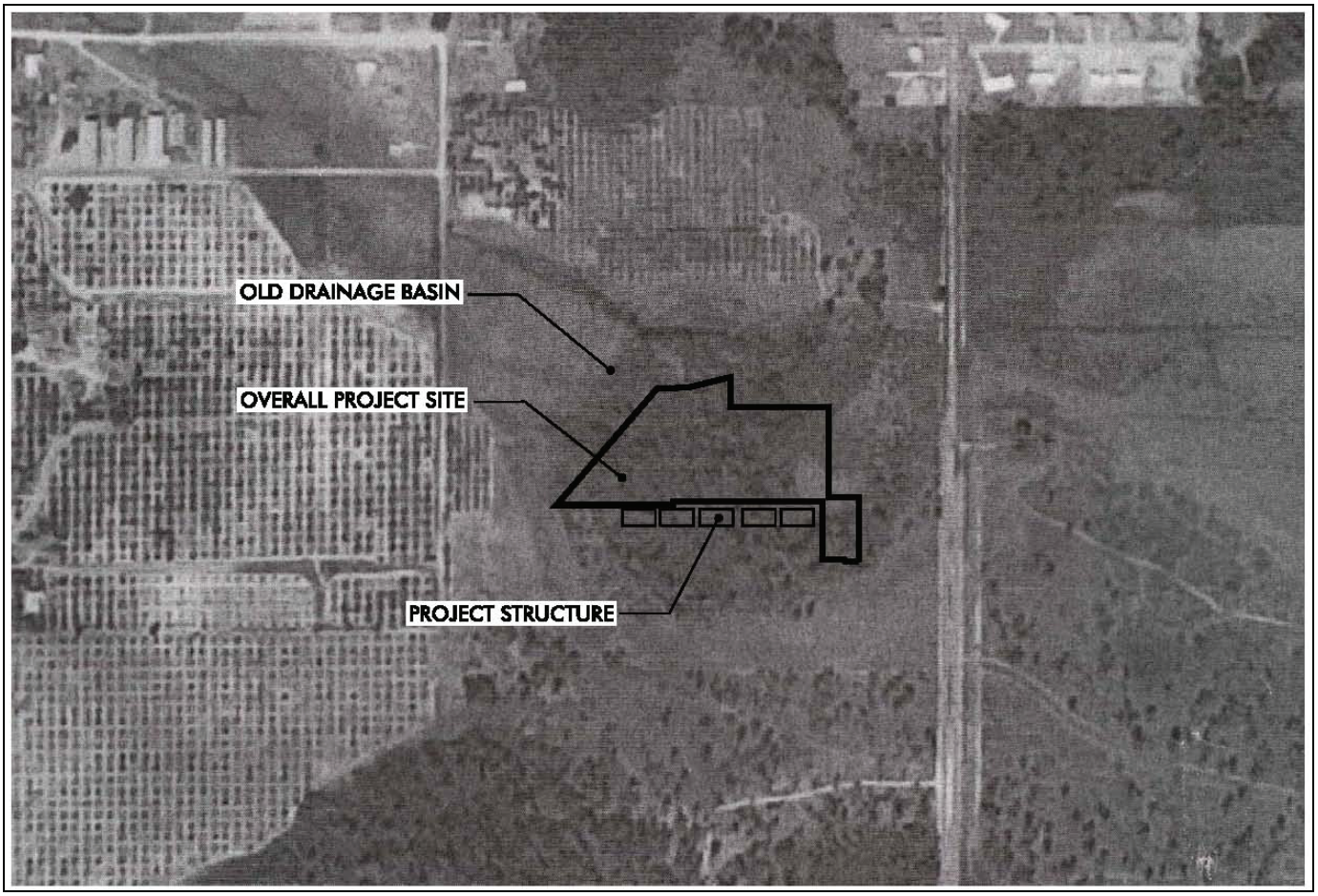

Fig. 12. Site aerial photograph of 1952 illustrating drainage basin and resulting relic sinkhole.

Concluding remarks

1. the owner reported that the damage had been ongoing since the building was constructed, which is consistent with a concrete slab supported by very loose, compressible, debris laden organic soils. The pile supported perimeter walls supported by the timber pile showed very little damage, indicating that no significant differential movement of the perimeter wall has yet occurred.

2. it was determined that deleterious soil condition was known to exist prior to construction of the building and is the reason that a pile foundation was recommended by the project geotechnical engineer. However, the foundation design only accounted for support of the perimeter walls and did not address the need for support of the slab. It was concluded that this design flaw/oversight was the primary reason that the building had sustained substantial interior damage.

3. it was also concluded that no feasible and effective options were available to remedy the relic sinkhole condition and that the wetland site over deposit of very deep organic soil was not a suitable site for this building construction.

4. additionally, as a direct result of structural and geotechnical engineer's severe design deficiency, as well as contractor's failure to exercise due care the building had sustained substantial irreversible damage.

5. the property owner's claim to the developer/builder was successful and the author understands that the owner was able to recover a major portion of the damage cost resulting from design oversight and relic sinkhole related damage.

CASE HISTORY TWO – PROJECT DESCRIPTION

This case history identifies a residential site failure. It assisted in litigation and resolution of legal issues.

Project specifics and forensic facts summary:

- the backyard slope of a one-story dwelling subsided abruptly, failed, and slid into the lake along with the rip-rap from lake edge. It also extended into the neighboring property on the south side.

- the lakefront backyard of a residence was damaged and stability of the structure was threatened.

Salient features of this case history are illustrated in Fig. 13 through 16.

Fig. 13. Panoramic view of the affected residences.

Fig. 14. View of backyard and subsided slope looking south.

Fig. 15. View of sodded and finished backyard.

Fig. 16. Reoccurrence of slope failure in finished backyard.

Forensic Field Exploration and Subsurface Condition Evaluation

Subsurface conditions beneath the site were evaluated by advancing several test borings. Typical subsurface conditions, as illustrated in Fig. 17, consisted of very soft, loose low strength subsoils to 15 ft depth. These low strength subsoils consisting of highly plastic clays (mc 113%, LL-107, PI-89) which were unstable under the weight of the additional fill material.

Slope stability analyses were performed for the original subsurface profile as well as the contractor/developer proposed restructured slope that yielded Factors of Safety (F.S.) of 0.87 and 0.93, respectively, for the two conditions.

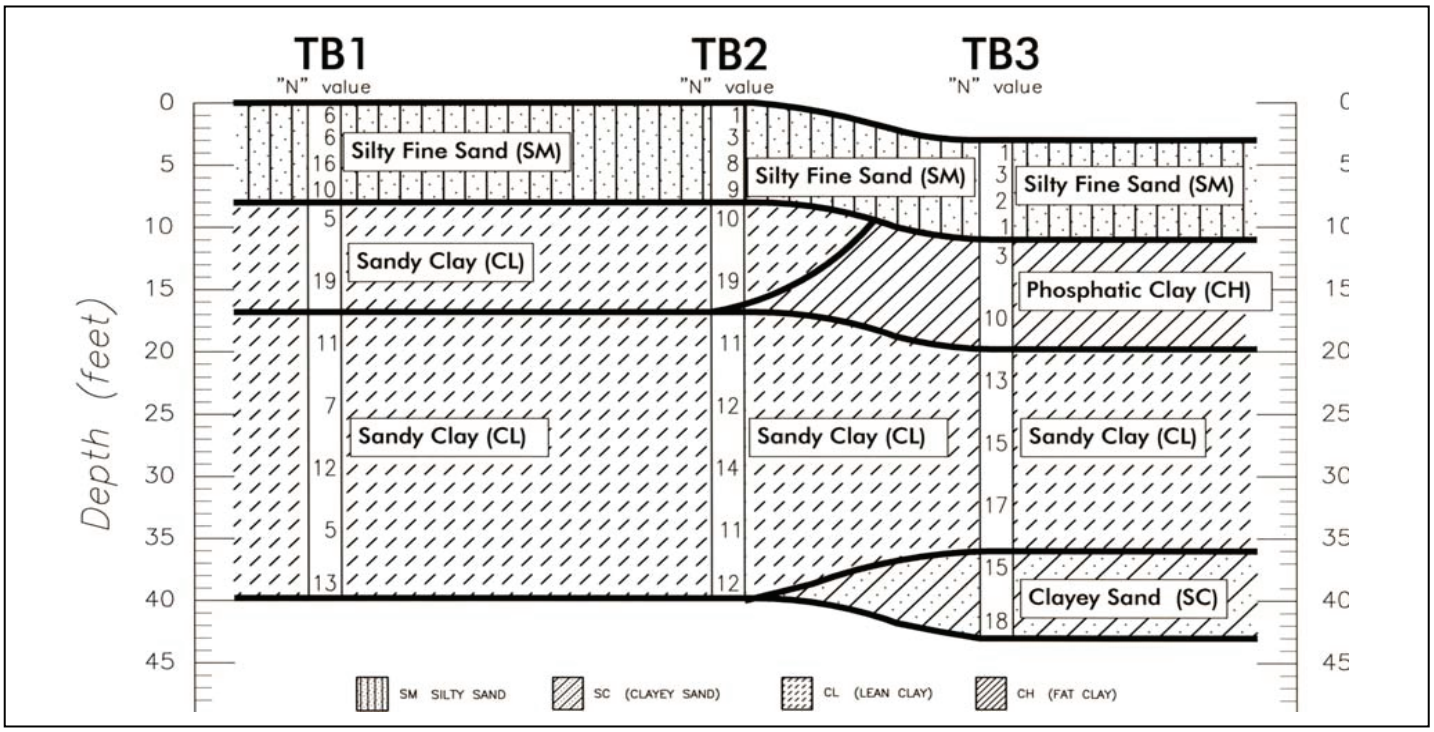

Fig. 17. Subsurface stratigraphy identifying delineation of compressible phosphatic clay.

Observations and Findings

The expert's investigation at the project development site revealed that:

- slope failure was triggered by the presence of unconsolidated sediment layers under the site fill.
- unstable sediments will continue to consolidate resulting in continued movement of the back of the house and the backyard.
- a retaining wall should have been constructed prior to the house being built to contain and stabilize the soils beneath the house foundation.

Upon the advice of their legal counsel the owner put the developer on notice, and elected to proceed with the proper fix pending resolution of litigation and the claim.

Remediation

Based on findings and observations from the FGE investigation, a two part remediation program was recommended and consisted of:

1. installation of helical anchor piers under the exterior wall footing, along the back of the house, for the underpinning stabilization.
2. installation of a helical anchor bulkhead to stabilize the backyard along the lake.

Various sequences of the underpinning and bulkhead stabilization program are illustrated in Fig. 18 through 23.

Fig. 18. View of support cap and bracket assembly under the footing.

Fig. 19. Hydraulic set-up for achieving torque/resistance capacity.

Fig. 20. View of bulkhead construction looking North.

Fig. 21. View of the completed timber bulkhead looking South.

Fig. 22. Geotextile being anchored into fill.

Fig. 23. View of completed bulkhead and restored backyard.

Concluding remarks

1. following close coordination between the forensic geotechnical engineer, the owner, and the remediation contractor and based upon results of remediation monitoring it was determined that the repair of the residence structure had been achieved satisfactorily.

2. the final repair resulted in restoration of the residential structure and backyard to it's originally planned and constructed stage, as illustrated in Fig. 23.

3. as a result of the monitored and satisfactory remediation program, the consultant recommended acceptance of the restored structure.

4. the property owner retained an attorney who sent a notice of claim and remediation cost summary to the developer/builder. It is the author's understanding that the property owner was able to recover these remediation costs along with attorney fees during the mediation process.

ACKNOWLEDGEMENTS

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